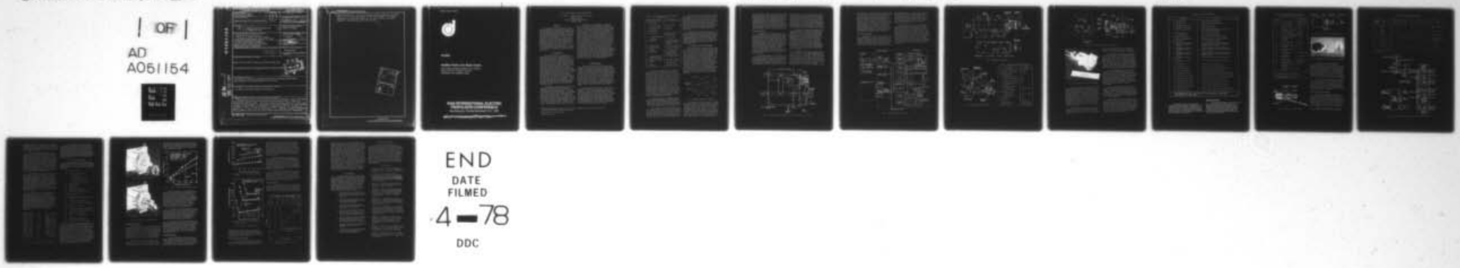
AD-A051 154 HUGHES RESEARCH LABS MALIBU CALIF F/G 22/2
SATELLITE POSITIVE ION BEAM SYSTEM.(U)
NOV 77 T D MASEK, H A COHEN F19628-76-C-0066
UNCLASSIFIED AFGL-TR-77-0240 NL

| OF |
AD
A051154



END
DATE
FILMED
4-78
DDC

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

AD A051154

19

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: 18 AFGL-TR-77-0240	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): 6 SATELLITE POSITIVE ION BEAM SYSTEM.	1	5. TYPE OF REPORT & PERIOD COVERED: 9 Rept. for SCIENTIFIC 1 Oct 75-30 Sep 76
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): 10 T.D. MASEK, HUGHES RESEARCH LAB; H. A. COHEN, AFGL/LKB		8. CONTRACT OR GRANT NUMBER(s): 15 F19628-76-C-0066
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Hughes Research Laboratories, A Division of Hughes Aircraft Company, 3011 Malibu Canyon Road, Malibu, CA 90265		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: P.E. 62101F; 16 JOCAS: 669001AP; 17 01
11. CONTROLLING OFFICE NAME AND ADDRESS: Air Force Geophysics Laboratory, Hanscom AFB, Massachusetts 01731, Monitor/Herbert Cohen/LKB		12. REPORT DATE: 11 2 Nov[redacted]977
		13. NUMBER OF PAGES: 13
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 12 15p.		15. SECURITY CLASS. (of this report): UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

DDC
MAR 14 1978
F

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Presented at the AIAA International Electric Propulsion Conference, Key Biscayne, Florida/November 14-17, 1976

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Ion Beam, Spacecraft Charging, Neutralizer

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Satellite Positive Ion Beam System (SPIBS) instrument is being developed as a charge ejection payload for the Air Force Satellite P78-2 (Satellite Charging At High Altitude). SPIBS will allow controlled ejection of xenon ions as part of the systematic investigation of satellite charging. Ion Beam currents of about 0.3 and 1.0 mA are obtained at a beam voltage of 1 kV; currents of about 0.7, 1.4, and 2.0 mA are obtained at 2 kV. Redundant filament neutralizers are provided to allow full or partial beam neutralization and an independent

AD No.
DDC FILE COPY

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED 172 600

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) source of electrons. These neutralizers can be biased at ten levels from -1 kV to +1 kV with respect to satellite ground. This paper describes the engineering model design, and presents ion source, expellant, and power processor test results.

AFGL-TR-77-0240

76-1054

Satellite Positive Ion Beam System

T.D. Masek, *Hughes Research Labs, Malibu, Calif.; and* H.A. Cohen, *Air Force Geophysics Lab, Bedford, Mass.*

AIAA INTERNATIONAL ELECTRIC PROPULSION CONFERENCE

Key Biscayne, Florida / November 14-17, 1976

SATELLITE POSITIVE ION BEAM SYSTEM*

T. D. Masek,** Hughes Research Laboratories
Malibu, Calif.;
and H. A. Cohen,†
Air Force Geophysics Laboratory,
Bedford, Mass.

Abstract

The Satellite Positive Ion Beam System (SPIBS) instrument is being developed as a charge ejection payload for the Air Force Satellite P78-2 (Satellite Charging At High Altitude). SPIBS will allow controlled ejection of xenon ions as part of the systematic investigation of satellite charging. Ion Beam currents of about 0.3 and 1.0 mA are obtained at a beam voltage of 1 kV; currents of about 0.7, 1.4, and 2.0 mA are obtained at 2 kV. Redundant filament neutralizers are provided to allow full or partial beam neutralization and an independent source of electrons. These neutralizers can be biased at ten levels from -1 kV to +1 kV with respect to satellite ground. This paper describes the engineering model design, and presents ion source, expellant, and power processor test results.

I. Introduction

Measurements made on satellites at synchronous altitude have shown that the surfaces of these spacecraft have occasionally become highly charged owing to energetic electrons in the ambient.[1,2] Spacecraft ground potentials of the order of tens of kilovolts relative to the ambient plasma have been seen, with the highest charging occurring during the periods in which the spacecraft was not directly illuminated by the sun. Observations of the performance of equipment on satellites in synchronous orbit have indicated that serious equipment damage occurs because of spacecraft charging.[3] A general program is now underway to study the entire spacecraft charging phenomenon.[4] A specific part of this program is the direct measurement at synchronous altitude of the causes of, the results of, and possible corrective measures for, spacecraft charging. To make these specific studies at synchronous altitude a satellite, SCATHA (Spacecraft Charging at High Altitude), is to be put into a near synchronous orbit during 1978.

In addition to instrumentation to accurately measure the ambient plasma[4] and spacecraft charging, the satellite payload will include two charged-particle ejection systems. It is planned to use these systems to investigate, in a controlled manner, the results of spacecraft-to-ambient-plasma potential differences, and methods of controlling spacecraft charging. An electron gun is to be used to swing the vehicle positive or to return the vehicle potential to ambient potential. The Satellite Positive Ion Beam System, SPIBS, will be used to emit electrons, beams of positive ions, or beams containing both positive ions and electrons.

The object is to make SPIBS an instrument that can be used to create a number of different spacecraft ground-to-ambient plasma potential differences. Each of these different charge ejection modes includes a range of both emitted current and particle energy modes. With these choices, controllable by ground command, it is expected that SPIBS will be used to swing the spacecraft ground either positive or negative with respect to the ambient plasma. In conjunction with other SCATHA payloads, it will also be used to investigate a variety of techniques of returning or maintaining spacecraft ground near the potential of the ambient plasma. The major determinants of SPIBS design come from two directions; the minimum performance specifications come from an analysis of published results of measurements on the synchronous satellites ATS-5 and ATS-6;[5,6] the SCATHA satellite design then imposed the limitations on the maximum weight and power of SPIBS. The fact that the design, construction, and testing of SPIBS was to occur concurrently with the design of the entire SCATHA payload, played an important role in determining the final form of SPIBS. Certain design factors had to be frozen early in the program to allow SPIBS to be included as a SCATHA payload.

II. Requirements

There is a body of evidence that spacecraft photoelectron emission plays a major role in determining the charging of satellites at synchronous orbit altitude.[1] To provide a mechanism to significantly change the SCATHA spacecraft ground potential during periods of solar illumination of the satellite, ion beam current levels were chosen so as to be greater than the maximum photoelectron emission expected from SCATHA spacecraft grounds. The requirements for ion beam current were set at 0.3 mA, 1 mA, and greater than or equal to 2 mA. The upper value was chosen to provide a dynamic range for possible ion beam currents consistent with power and weight limitations. Other requirements are summarized in Table 1.

Ion beam particle energies of 1 and 2 keV were specified to allow for a large swing in spacecraft potential. The specification for minimum operating lifetime was first set at 100 hours and, as the program developed, was increased to 300 hours. Emphasis was placed on the requirement that this lifetime be achievable through a large number of discrete operating periods. The relatively short operating lifetime requirement, coupled with the desire to take all measures possible to avoid chemical contamination of SCATHA surfaces, led to the requirement that a noble gas be used as the source of ions.

*This work was supported under Air Force Contract F19628-76-C-0066, Air Force Systems Command, Air Force Geophysics Laboratory.

**Head, Thruster Systems Section

†Program Manager

Table 1. SPIBS Performance and Functional Requirements

Function/Parameter	Requirement
1. Ion ejection	
a. Current range	0.3 to 2.0 mA
b. Energy range	1 to 2 keV
2. Expellant type	Noble gas
3. Neutralizer	
a. Control	Operable with ion beam on or off
b. Emission range	2 μA to 2 mA
c. Biasing	-1 kV to +1 kV
4. Decel grid	Avoid high voltage surfaces exposed to space
5. Operating life	300 hours minimum
6. On/Off cycles	200 cycles minimum
7. Weight	7.8 kg maximum
8. Input power	60 W maximum starting; 30 W maximum operating
9. Vacuum enclosure and blowoff cover	Pre-flight testing
10. External magnetic field	Less than 1 gauss at 10 cm from source
11. EMI	MIL STD 461 A
12. Vibration	20 g RMS random

A variety of different uses for SPIBS is made possible by including a biasable filament, which could be used as a beam and/or spacecraft neutralizer when operated in conjunction with the ion source. This biasable filament can also be used independently as an electron source and therefore as a satellite neutralizer. The maximum emission current required from this filament is 2 mA, the maximum ion beam current which had to be neutralized. The minimum emission current, 2μA, was chosen in order to have a wide dynamic range of controllable emission levels. During the SPIBS development the number of controllable steps of either filament current or bias, was determined by weight, power and packaging considerations. An explicit decision was made to measure not only the ion beam current and the current emitted by the heated filament, but also the net current emitted from SPIBS.

In order to minimize interference with other SCATHA experiments, the SPIBS structure exposed to the ambient plasma had to be kept close to spacecraft ground potential. This translated into the requirement of a grounded-surface (decel grid) following the ion accelerator grid.

One further element that contributed to the final design of SPIBS was the desire to be able to operate the instrument during spacecraft integration and during some stages of satellite pre-launch testing. To allow for this, a requirement was imposed that SPIBS be designed to operate in conjunction with a portable vacuum pumping system.

The weight and power limitations on SPIBS were changed several times during the design and testing due to a variety of causes. One cause was the requirement for satellite integration; and the other, the usual one, the need for more power and weight to meet ambitious operational goals. The final values which played a major role in SPIBS design were a packaged weight of less than 7.8 kg and an input power of less than 60 watts during start up and less than 30 watts during normal operation.

In conformity with SPIBS requirements, a breadboard model has been built and tested. Test results indicating that all functional requirements have been satisfied are described herein. Designs for the engineering and flight models have been completed along with test results for certain engineering model (EM) components. The EM is currently in fabrication and will be used as the qualification model.

III. SPIBS Instrument Description

The requirements and goals outlined in the previous section led to the system shown schematically in Fig. 1. The basic system consists of an ion source assembly, an expellant assembly, and a power processor. Xenon gas is delivered to the porous plug in the source at 20 psia through a pressure regulator and latching valve from a reservoir initially charged to about 900 psig. Power for the ion source valve, analog telemetry, and command functions are provided by the power processor assembly (PPA). The PPA circuitry is packaged on conventional circuit cards within a structural enclosure. An ion source vacuum enclosure, with a cover that is opened by use of electroexplosive devices, provides protection for the ion source prior to operation in space. This blowoff cover is designed to allow for complete ground checkout of ion source and system prior to launch.

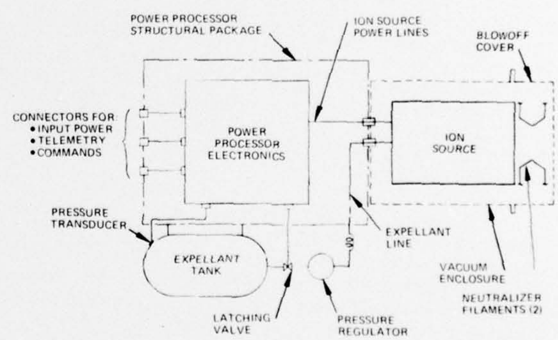


Fig. 1. SPIBS functional block diagram.

Ion thruster technology was used to develop the ion source in the areas of ion optics, cathode, discharge chamber, and expellant line high voltage isolation. Positive xenon ions extracted from a Penning-type discharge plasma are accelerated electrostatically to high velocity. The discharge is operated at the beam potential to allow the ions to exit at near-ground potential. In the discharge plasma, ions are formed by collisions between atoms and electrons. A conventional hollow cathode is used to generate the electrons which are then accelerated into the plasma by means of the discharge voltage. An axial magnetic field is used to restrict electron flow radially and increase electron-atom collisions. Downstream of the ion accelerating grids is a neutralizer in the form of redundant thermionically-emitting filaments. Depending upon the satellite experiment requirements, the neutralizer could be used to neutralize all or a fraction (including zero) of the ion beam. The neutralizer can be biased to ±1000 V to control satellite potential relative to the space plasma.

System Description

A SPIBS schematic diagram is shown in Fig. 2 to indicate the general electrical interconnections between the ion source and PPA. Additional system functions and interfaces are illustrated in Fig. 3. These figures show the locations of key measurements, current paths, and the grounding approach. Layout and isometric drawings are presented in Figs. 4 and 5 respectively to illustrate the SPIBS instrument configuration. Overall dimensions of the package are 49 x 23 x 13 cm and the engineering model weight is 7.4 kg. Several features of the blowoff cover can be noted, including the open and closed positions, and the ion beam collector to be used during ground checkout.

Major characteristics of the SPIBS instrument are presented in Table 2. Ion current range and energy are consistent with the requirements discussed previously. Input power levels shown are based on testing experience with the breadboard ion source and PPA. The ion source can be operated with or without the neutralizer, and the neutralizer can be operated without the ion beam. Five neutralizer electron emission levels from 2 μA to 2.2 mA can be obtained. For additional flexibility in studying satellite potential control, the neutralizer can be biased at ten levels from -1000 to +1000 V with respect to satellite ground (telemetry return). The minimum operating life and on/off cycle requirements have been demonstrated with the breadboard system. The expellant reservoir is sized for 2000 hours of operation.

Command capability being implemented is indicated in Table 3. A total of 29 ground commands provides great flexibility in SPIBS flight operation, as well as allowing for convenient ground testing. The cathode can be heated at either of two levels, corresponding to initial conditioning of a new cathode (level 2) or lower-power normal startup (level 1). Commands 6 and 7 turn on the cathode keeper, beam, and accel power supplies. For evaluation testing, these supplies can be turned off separately by commands 10 and 28 respectively. Through commands 16 and 17, the neutralizer heater supply can be connected to either of the redundant filaments as desired.

Analog telemetry outputs are provided as shown in Table 4. These eighteen outputs allow a relatively complete evaluation of SPIBS operation and performance. Except where noted, the telemetry is expected to be accurate to ±5% over the normal operating range. Higher accuracy is provided for the beam current since this is one of the most important measurements. Two other important measurements, produced by bipolar electrometers, are provided by channels 13 and 14.

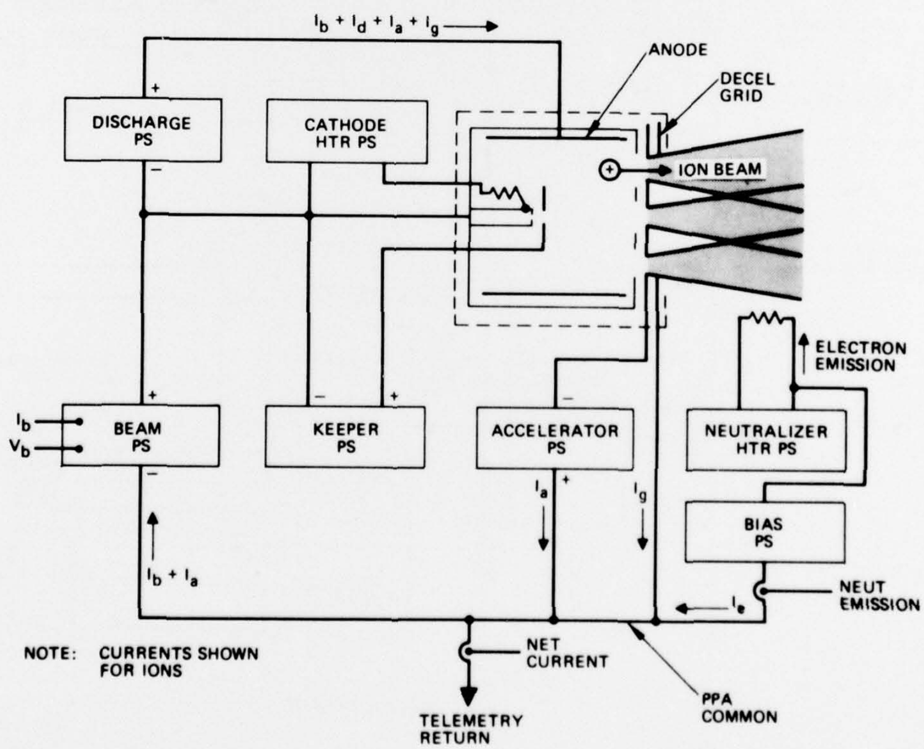


Fig. 2. SPIBS schematic diagram for ion source and power processor.

The electrometers are designed to operate between -2.5 mA and +2.5 mA (plus corresponds to a net electron flow out of the filament). The bipolar feature is required only for detecting the net current to ground, but the two electrometers are identical to simplify design and fabrication. For currents (positive or negative) greater than 2 μA, the electrometer outputs will be accurate to ±10% of the true current. In addition to the primary outputs defining source operation, telemetry is also provided for expellant reservoir pressure, and PPA housekeeping. Not listed in Table 4 are two flags used for defining bias voltage polarity, and blowoff cover position (open or closed).

Ion Source Assembly

The SPIBS ion source assembly (ISA), as illustrated in Fig. 6, includes the ion source and neutralizer filaments, and a vacuum enclosure endplate. The major elements of the source are (1) ion optics with redundant neutralizer filaments, (2) source body which supports the magnets and anode, and (3) cathode-isolator-porous plug (CIP). The CIP supports the keeper, and interfaces with the expellant assembly. A photograph of the breadboard ion source is shown in Fig. 7 and is reasonably representative of the engineering model and flight model configurations. The photo does not show the single aperture in the decel grid, double shields on optics insulators, and minor fabrication details.

The ion source is cantilivered from three insulated feedthroughs attached to the vacuum enclosure endplate. The feedthroughs are tilted towards the center line of the source at a 10^{o} angle forming a rigid conical support base. This configuration allows the endplate to remain small while providing sufficient clearance for the isolator assembly, which lies within the conical space formed by the three insulators. Nine wiring insulator feedthroughs are arranged in a circular pattern around the enclosure endplate. These are also tilted towards the axis to allow sputter shields to be placed on the source end of the electrical feedthroughs.

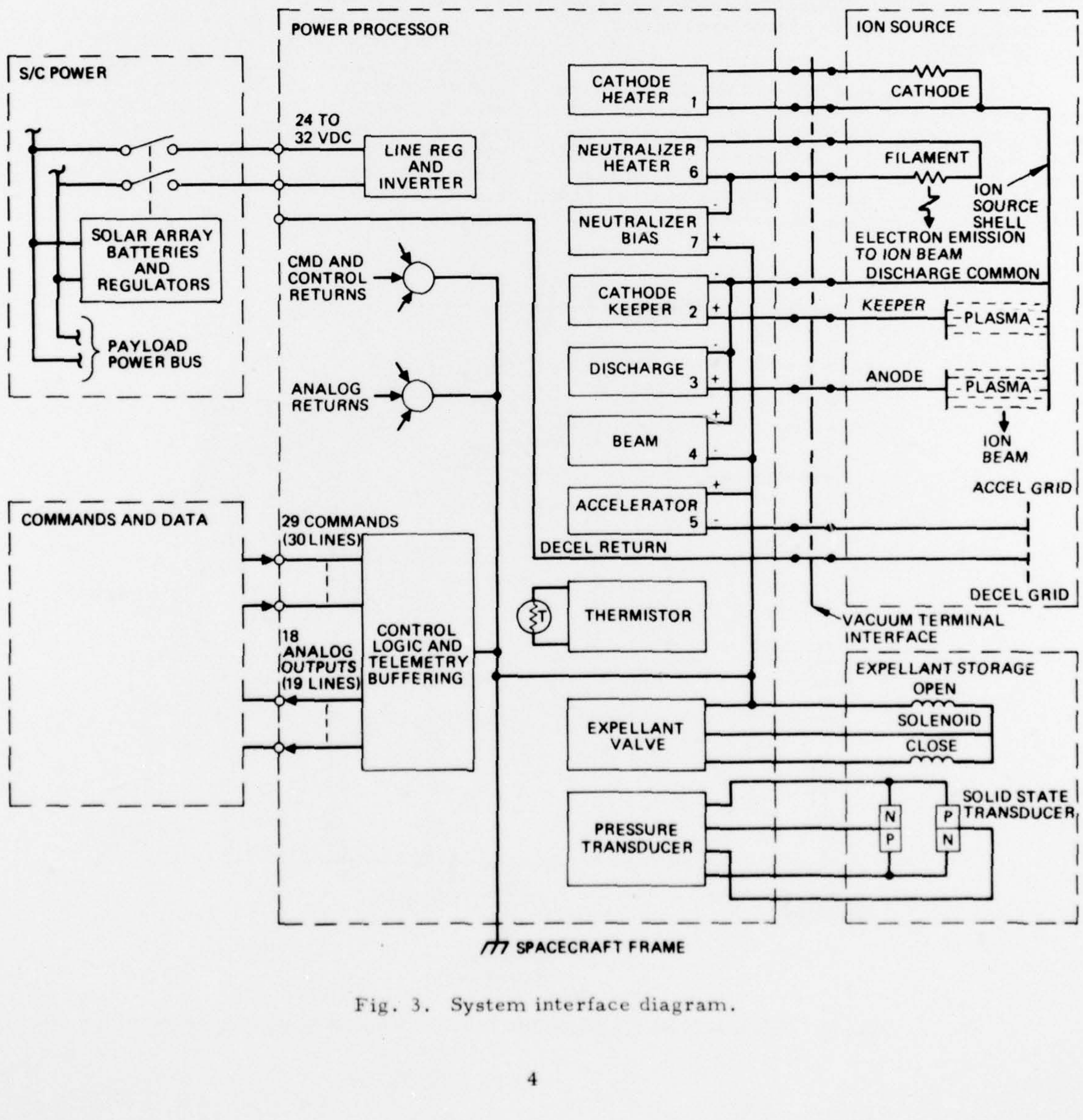


Fig. 3. System interface diagram.

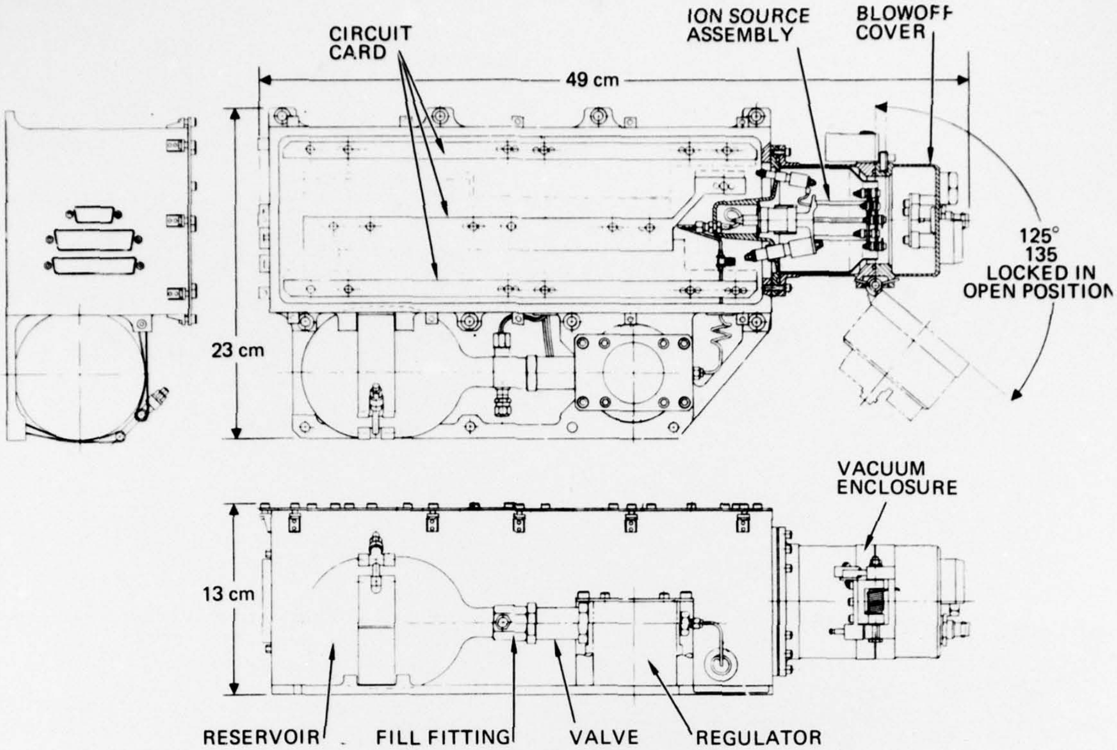


Fig. 4. SPIBS layout drawing.

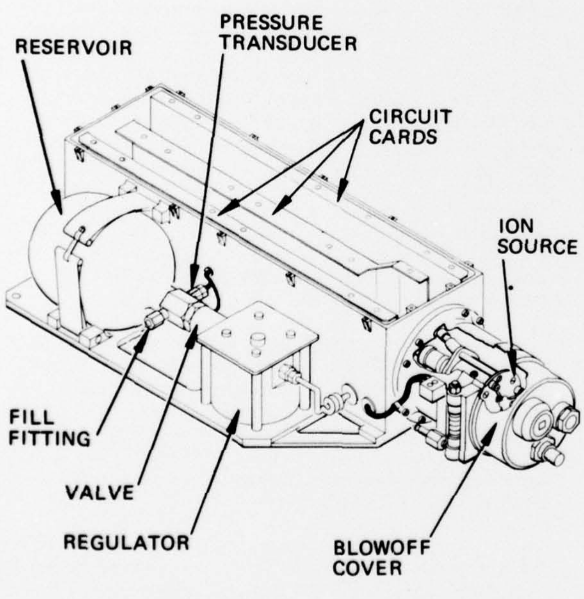


Fig. 5. SPIBS isometric drawing.

Table 2. SPIBS Instrument Characteristics

Parameter	Value
1. Ion beam current, MA	0.3 to 2.0
2. Ion beam energy, KeV	1 and 2
3. Input power, W	
a. Maximum start up	60
b. Beam of 1 mA at 1 kV	30
c. Beam of 2 mA at 2 kV	45
d. Full beam and biased neutralizer	60
4. Neutralizer emission	
a. Current range	2 μA to 2 mA
b. Number of levels	5
5. Neutralizer bias	
a. Voltage range	-1 kV to +1 kV
b. Number of levels	10
6. Weight, kg	7.4
7. Size, cm	49 x 23 x 13
8. Operating life, H	300 minimum
9. On/Off cycles	200 minimum

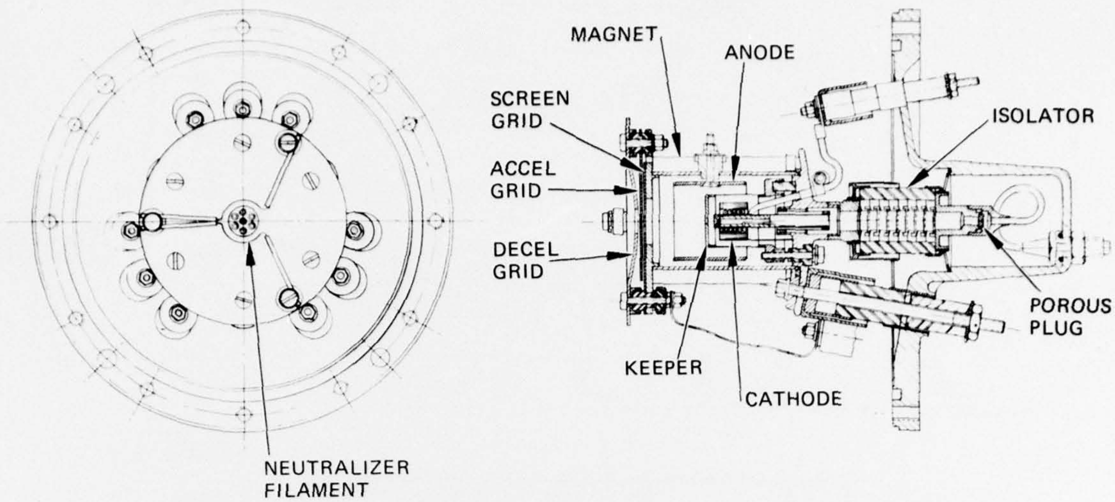


Fig. 6. Ion source assembly layout drawing.

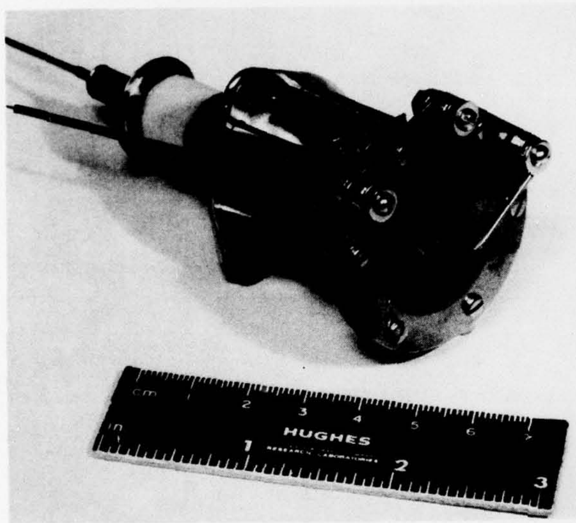


Fig. 7. Breadboard ion source photograph.

The ion optics design incorporates several novel features, including a single-aperture steel decel grid, and graphite screen and accel grids. Steel was selected for the decel to reduce the external magnetic field. Graphite was selected for the screen and accel grids to minimize charge exchange sputtering. A single-aperture decel grid was selected to minimize the trapping of sputtered accel material which in early tests was found to cause a significant buildup on the decel and subsequent shorting. The screen and accel supplies can operate into a short, therefore a "recycle" or "high voltage trip" is not included in the PPA design.

The neutralizer filaments are mounted from the decel grid using shielded insulators. The filament material is tantalum with yttrium added to reduce brittleness.[7] A filament length of 1.27 cm and a diameter of 0.18 mm has been found to combine low heater power, adequate emission, and reasonable operating temperature.

The cathode-isolator-porous plug (CIP) subassembly makes use of the technology developed for the 8-cm mercury thruster.[8,9] Xenon gas flowrate to the source is determined mainly by the porous plug, which reduces the pressure from 20 psia to a few Torr. The porous plug is fabricated from tungsten with a density of 80%, is 0.32 cm in diameter, and is about 0.14 cm thick. The plug is electron-beam welded into a tantalum housing, with the sides electron-beam sealed so that the gas flows through the full plug thickness.

The high voltage isolator consists of an Al_2O_3 outer shell flanged on both ends, with alternating ceramic rings and stainless-steel mesh disks within the inner passage.[8,9] The disks function as barriers to electrons accelerated by the electric field gradient. Within each gap, the applied field gradient is below the minimum required for Paschen breakdown. The flanges provide a means for attaching the isolator to the porous plug (upstream) and the cathode (downstream).

The structural part of the isolator subassembly is the alumina outer housing. Since alumina is capable of withstanding very limited bending or tension loads, the isolator is mounted in compression. Compressive loading of the isolator housing is provided by the belleville washer between the upstream flange of the isolator and the enclosure endplate.

The cathode design is illustrated in Fig. 8. This cathode is similar to the 5-cm and 8-cm ion thruster cathodes with a modified mount.[8,9] The cathode assembly is designed to include a reentrant type mount which has the effect of increasing the thermal conduction path length and decreasing the thermal loss. The cathode is mounted to one end of a central passage through the endplate of the source body. The other end of the central passage is attached to the isolator.

Table 3. Command Capability

Command	Function
1. Instrument on*	Turns on instrument power
2. Instrument off*	Turns off all instrument power
3. Expellant valve open	Opens solenoid valve
4. Expellant valve closed	Closes solenoid valve
5. Cathode heater preheat	Turns on the cathode heater to Level 1 and turns on discharge supply
6. Ion gun power on	Turns on the ion gun power
7. Ion gun power off	Turns off the ion gun power
8. Beam voltage Level 1	Sets the beam power supply to 1000 V
9. Beam voltage Level 2	Sets the beam power supply to 2000 V
10. Keeper off	Turns the keeper supply off
11. Discharge current and neutralizer emission Level 1	Sets the discharge current reference to achieve 20 mA current; sets neutralizer emission level to 0.4 mA
12. Discharge current and neutralizer emission Level 2	Sets the discharge current reference to achieve 125 mA; sets neutralizer emission level to 1.2 mA
13. Discharge current and neutralizer emission Level 3	Sets the discharge current reference to achieve 200 mA; sets neutralizer emission level to 2.2 mA
14. Neutralizer emission Level 4	Sets neutralizer emission level to 2 μA
15. Neutralizer emission Level 5	Sets neutralizer emission level to 20 μA
16. Neutralizer No. 1	Selects neutralizer filament No. 1
17. Neutralizer No. 2	Selects neutralizer filament No. 2
18. Neutralizer heater on	Turns on the neutralizer cathode heater on
19. Neutralizer heater off	Turns off the neutralizer heater
20. Neutralizer bias off	Turns off the neutralizer bias power supply
21. Neutralizer bias positive	Sets the neutralizer bias for positive polarity
22. Neutralizer bias negative	Sets the neutralizer bias for negative polarity
23. Neutralizer bias Level 1	Turns on the neutralizer bias to 10 V
24. Neutralizer bias Level 2	Turns on the neutralizer bias to 25 V
25. Neutralizer bias Level 3	Turns on the neutralizer bias to 100 V
26. Neutralizer bias Level 4	Turns on the neutralizer bias to 500 V
27. Neutralizer bias Level 5	Turns on the neutralizer bias to 1000 V
28. High voltage off	Turns off the beam and accel power supplies
29. Cathode conditioning	Turns on the cathode heater to Level 2

*In the SPIBS instrument, "instrument on/off" is implemented by connecting or disconnecting 28 = V input power.

The cathode insert is made of oxide-impregnated porous tungsten. Attachment to the cathode tube is accomplished through four rhenium wires that are brazed to the insert and spot welded to the tube. This approach was selected after evaluation of rolled tantalum foil inserts and other impregnated configurations.

Expellant Assembly

The expellant assembly (EA) stores, regulates, and delivers xenon to the ion source assembly at a pressure of 20 ±2 psia. At this pressure the porous plug in the CIP limits the flowrate to about 25 scc/hr (25 mA equivalent). A drawing of the EA is presented in Fig. 9 to indicate the design approach; individual components are shown in Fig. 10.

Table 4. Analog Outputs (Telemetry) and Actual Value for Full Scale (5 V)

Channel No.	Description	Actual Value for 5 V Output, ± 5%
1	Beam current	2.5 mA (± 2%)
2	Beam voltage	2500 V
3	Discharge current	250 mA
4	Discharge voltage	50 V
5	Keeper current	250 mA
6	Keeper high voltage	1000 V
7	Keeper low voltage	50 V
8	Cathode heater current	5 A
9	Accel current[a]	2.5 mA
10	Decel current[a]	2.5 mA
11	Neutralizer heater current	5A
12	Neutralizer bias voltage	1000 V
13	Neutralizer emission[b]	2.5 mA (± 10%)
14	SPIBS net current[b]	2.5 mA (± 10%)
15	Tank pressure	1500 psia
16	Power processor temperature	See calib curve
17	PPA AC inverter current	1.5 A
18	PPA AC inverter voltage	50 V

[a]To indicate anomolous condition

[b]In three ranges: 2.5 to 25 μA; 25 μA to 250 μA; 250 μA to 2.5 mA

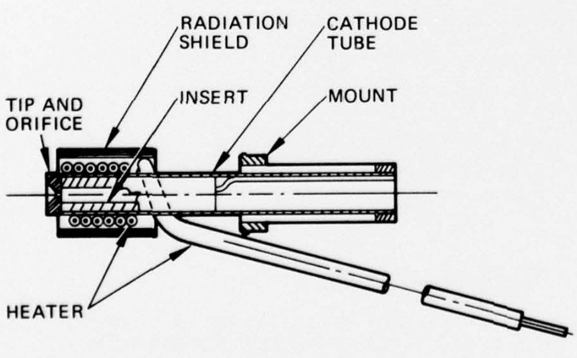


Fig. 8. Cathode assembly design.

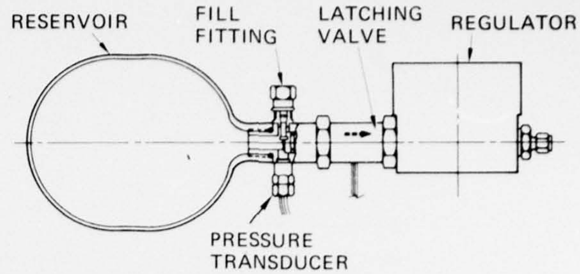


Fig. 9. Expellant assembly drawing.

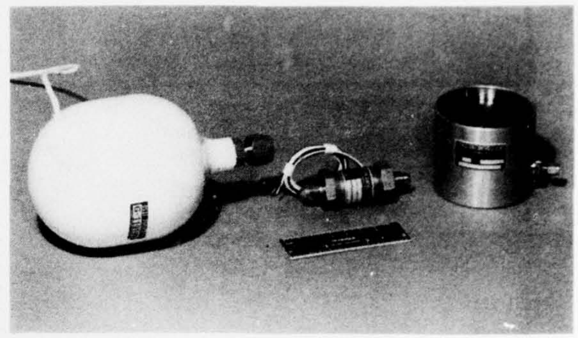


Fig. 10. Expellant assembly component photograph.

The reservoir is manufactured by Accessory Products Division of Hydraulic Research and Manufacturing and is a DOT rated commercial aircraft part. When filled to 900 psi, this reservoir contains about 50 standard liters of xenon. *At the design flowrate,* this will provide about 2000 hours of operation. Attached to the reservoir, as shown in Fig. 9, is a fitting used for filling and a pressure transducer. The semiconductor type transducer is built into a standard screw and is manufactured by Entran Devices, Inc.

The latching valve and pressure regulator are manufactured by Carleton Controls Corporation. The latching valve requires about 1.0 A at 28 V to open and about 0.1 A to close; power is applied for 100 ms. The regulator will control from the initial pressure of 900 psi down to less than 15 psi (30 psia). Thus, virtually all the gas in the reservoir can be utilized.

Power Processor Assembly

The function of the power processor assembly (PPA) is to operate and control the ion source, operate the expellant valve, provide telemetry data, and accept commands from the satellite. This section describes the design being implemented to meet the requirements shown in Table 5 and the characteristics discussed in previous sections. Simplicity, low cost, and minimum development risk have beem emphasized.

A functional block diagram of the PPA, shown in Fig. 11, indicates the general power

Table 5. Power Supply Requirements

Power Supply No.	Power Supply Name	Type	Maximum Voltage Relative to S/C GND, V	Maximum Power		Typical Power		Regulation ±%	Range of Control
				Current, A	Voltage, V	Current, A	Voltage, V		
1	Cathode Heater	AC	+2000	4.5	6	0	0	Loop	1.0 to 4.5 (I)
2	Cathode Keeper	DC	+2000	0.2	25[a]	0.15	20	5 (I)	0.05 to 0.2 (I)
3	Discharge	DC	+2000	0.20	40	0.13	30	5 (I)	0.01 to 0.20 (I)
4	Beam	DC	0	3×10^{-3}	2000	1×10^{-3}	1000	5 (V)	1000 to 2000 (V)
5	Accelerator	DC	0	1×10^{-3}	600	2×10^{-5}	300	5 (V)	Varies with beam voltage
6	Neutralizer Heater	AC	±1000	3	3	2.5	2.5	Loop	10 to 30 (I)
7	Neutralizer Bias	±DC	0	3×10^{-3}	1000	1×10^{-3}	0	5 (V)	±10 to ±1000 V

[a]1000 V open circuit

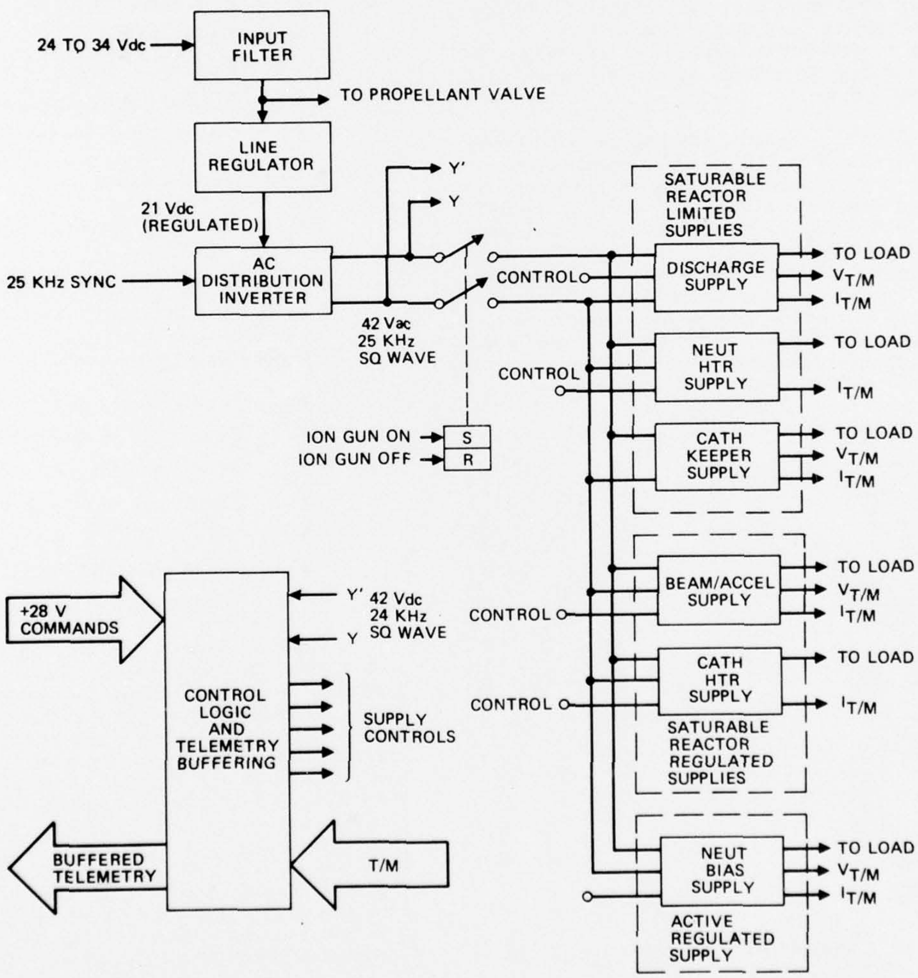


Fig. 11. Power processor assembly functional block diagram.

processing technique. Input power is first regulated at 21 V dc. A 25-kHz square-wave synchronized inverter then produces 42 V rms ac for each power supply. Saturable reactor-type power supplies are generally used.

The major feature of this design is the achievement of electrical isolation between the input power lines, the command lines, telemetry, and the outputs of the various supplies. The isolation of the command lines is obtained by using relays. The relay coils provide electrical isolation, and magnetic latching provides nonvolatile storage of the received commands. The isolation between input, output, and the telemetry lines is achieved by transformer. Each individual supply has an output transformer and, where required, includes isolated voltage-sense windings and a current transformer on the primary for voltage and current telemetry, respectively.

Supplies for discharge, neutralizer heater, and cathode keeper are fixed setpoint supplies, and are current limited by saturable reactor for short-circuit protection. The beam/accel and cathode heaters supplies use saturable reactors both for controllability and current limiting. The neutralizer bias supply is transistor regulated. The line regulator is a "buck" switching regulator which converts the unregulated 24-to-32-V input bus to regulated 21 V dc. An input filter is required to prevent the ripple current generated by the line regulator from appearing on the input power bus lines.

The PPA circuits are packaged on three cards, as shown in Fig. 5. Components are mounted on both surfaces of the magnesium channel-section structural member. A typical circuit card layout is shown in Fig. 12 and illustrates the packaging techniques. Both the terminal strips and magnets are bonded to the plate. Without magnetics mounting studs, a relatively large area is made available for component mounting. A qualification vibration test of a section of a typical loaded circuit card was successfully performed to evaluate this packaging approach.

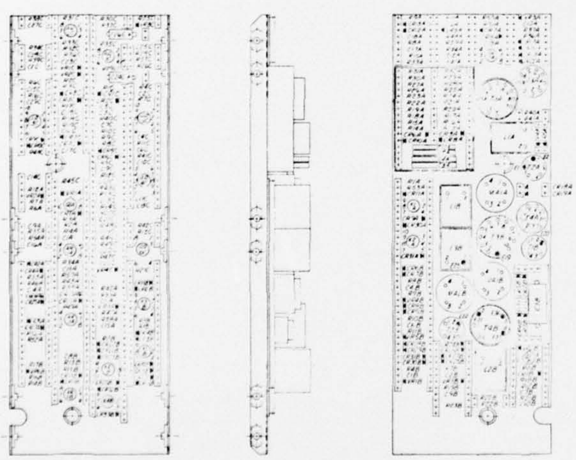


Fig. 12. Typical PPA circuit card layout.

The breadboard PPA has been tested against the electromagnetic interference (EMI) requirements of MIL STD 461A. Except for a few high frequency ranges, the SPIBS unit met the conducted emissions requirements; tests for input line susceptability were also successful. Although the EMI characteristics of the PPA may be slightly different in the packaged configuration, these tests showed that the filtering design is basically correct.

IV. SPIBS Test Results

A number of tests have been performed during the SPIBS development process to evaluate performance of various assemblies and to verify design techniques. The types of tests include the following:

Ion source assembly

- Electrical performance
  - Ion source
  - Neutralized ion source
  - Electron source
  - Biased electron source
- PPA integration
- Endurance
- Startup cycling
- Vibration of ion optics
- Operation in blowoff cover

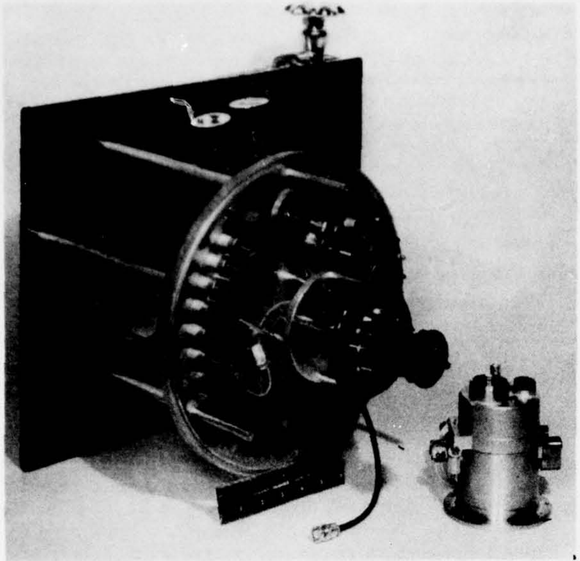
Expellant assembly

- Regulator performance with ion source
- Latching valve operation
- Pressure transducer calibration

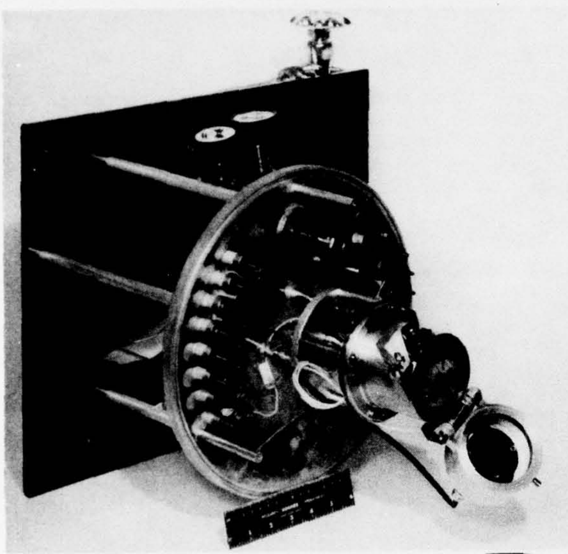
Power processor assembly

- Breadboard electrical efficiency
- Functional evaluation of all circuits
- Ion source integration
- Endurance using ion source
- EMI
- Commands and telemetry
- Sample circuit card vibration

The ion source test configuration is shown in Fig. 13. The first view, with the vacuum enclosure removed, shows the breadboard model ion source mounted on the vacuum enclosure end-plate. The second view shows the normal test configuration with the cover open. Tests were performed with the cover closed, using the graphite collector in the cover to measure ion current. With the cover closed, pumping occurs through the port seen in Fig. 13(a). In all tests, a ground shield is installed over the vacuum feed-through terminals. The regulator and latching valve were attached to the plate behind the vacuum flange. Tests were conducted with both lab-type power supplies and the breadboard PPA.



(a) Vacuum enclosure removed



(b) Vacuum enclosure installed with blowoff cover open

Fig. 13. Ion source test configuration.

Ion Source Assembly

Representative ion source performance data are shown in Fig. 14 showing beam current as a function of discharge current at two beam voltages. The desired beam current is obtained by selecting one of three discharge current levels. Since beam current also varies slightly with beam voltage, a total of six current levels can be obtained. Also illustrated in this figure is the fact that performance is relatively insensitive to keeper current.

Typical ion optics characteristics are presented in Fig. 15 showing (a) beam current versus total extraction voltage and (b) accelerator current versus total extraction voltage. Since total extraction voltage is the sum of the screen and accelerator voltages, the 1-kV and 2-kV beam voltage levels correspond to totals of 1.3 kV and 2.6 kV, respectively. Operation at all levels is below the perveance limit.

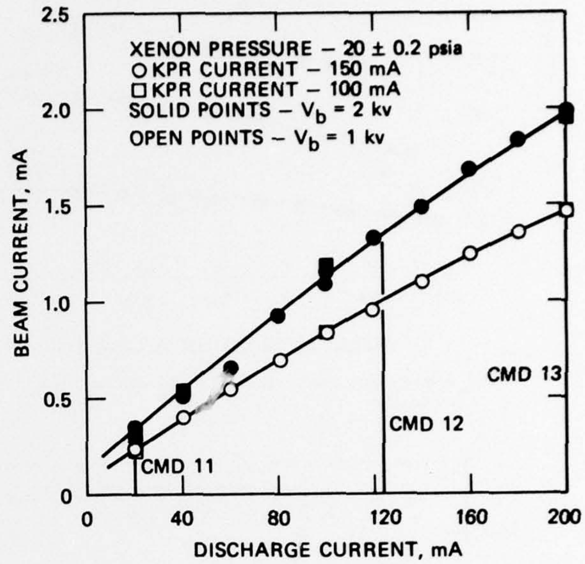


Fig. 14. Beam current versus discharge current.

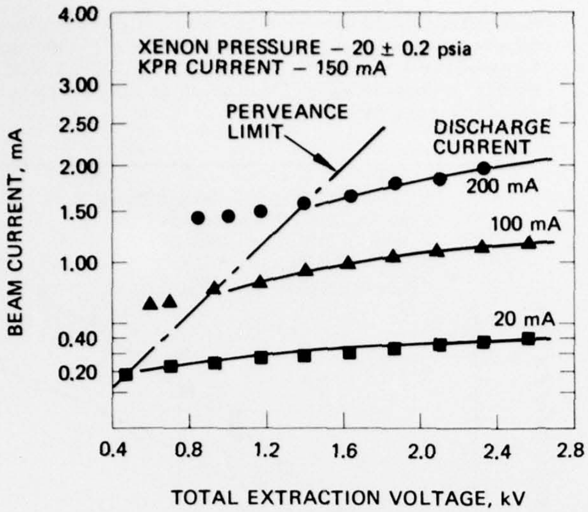
In terms of endurance, several tests of 200 to 300 hours duration were conducted to evaluate various aspects of the source design. A 600-hour test was then conducted to verify the engineering model ion optics design. In addition, startup (on/off) tests to evaluate cycling capability have been performed with several cathode insert configurations. Approximately 400 cycles were conducted with the EM insert design with no apparent change in characteristics. Most performance, endurance, and cycle tests were accomplished using the breadboard PPA.

A vibration test to qualification levels was performed on the ion optics subassembly mounted to a representative source body. The primary purpose of this test was to provide assurance that the graphite grids and tantalum filaments are satisfactory dynamically. No difficulties were encountered, and an engineering model optics-design baseline was thereby established.

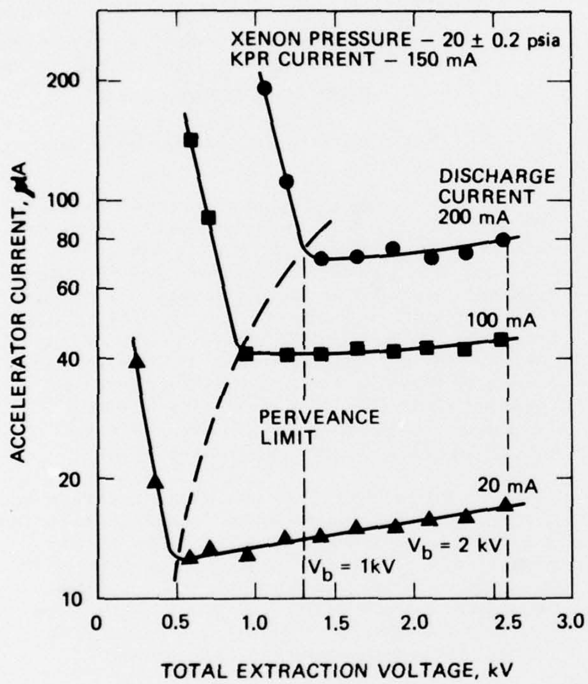
As a further verification of the engineering model system design, an ion source test was performed with the blowoff cover closed, but with the pumpout port open. This type of test simulated ground checkout operation in which a vacuum station will be used to pump the xenon gas through the cover pumpout port. Beam currents up to 1 mA with a beam voltage of 1 kV were obtained without difficulty.

Expellant Assembly

The critical portions of the engineering model expellant assembly have been successfully tested separately and with the ion source. Both the regulator and latching valve were used during the 600-hour ion source test. In that test, a standard lecture bottle was expended from about



(a) Beam current versus total extraction voltage



(b) Accelerator current versus total extraction voltage

Fig. 15. *Ion optics characteristics.*

600 psig down to about 10 psig. The pressure transducer type selected for the EM system was calibrated over the expected pressure range and was found to be stable within ±10% over a temperature range from -40 to +80°C.

Power Processor Assembly

The most lengthy testing of the PPA has occurred in conjunction with ion source endurance testing. Virtually all functional aspects of the PPA have been evaluated, including: (1) basic operation of the ion source over the full power range, (2) operation and control of the neutralizers, (3) biased operation of the neutralizer, (4) operation of both electrometers, (5) operation from simulated ground commands, and (6) calibration of telemetry outputs. Based on this relatively extensive testing of the breadboard, the PPA circuit design was finalized for engineering model fabrication.

The PPA packaging concept shown previously in Fig. 12 was evaluated dynamically. A 15-cm length of a circuit card was assembled using the proposed engineering model fabrication techniques. Magnetics and terminal strips were bonded to the magnesium plate, dummy components were installed and the card was conformally coated. A qualification level vibration test was conducted without incident.

EMI tests were performed on the breadboard for conducted emissions and susceptibility using MIL STD 461A as a reference. Filters added to the line regulator were found to satisfy the major requirements. Slight changes to the line regulator control response were implemented to meet susceptibility requirements.

System Operation

The SPIBS elements have been tested individually, in pairs, and as a system. A good indication of system performance is shown in Fig. 16 in which input power is presented as a function of operating mode. These data were taken with the

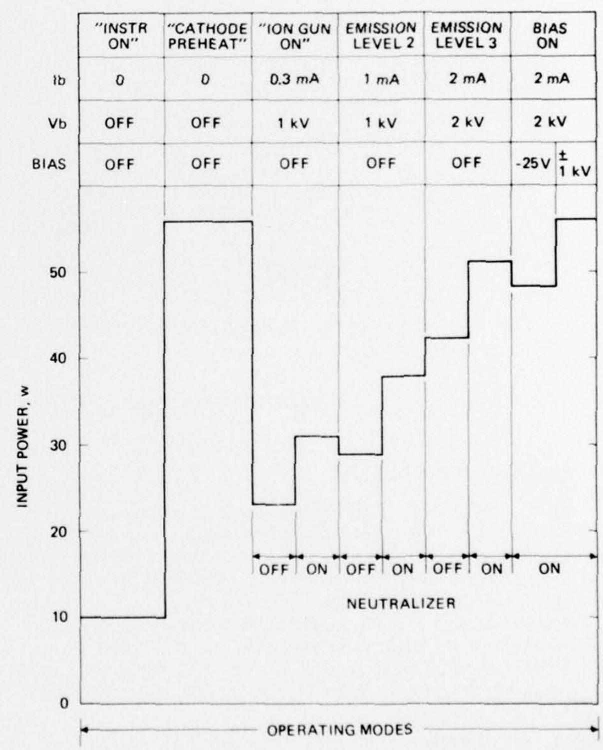


Fig. 16. SPIBS input power as a function of operating mode.

breadboard system. The first command "instrument on" activates the line regulator and ac distribution inverter to allow housekeeping functions to be monitored. The "cathode preheat" command turns on the cathode heater and discharge supply. After a period of a few minutes (1-5 typically), keeper voltage is applied and the discharge ignites. When the discharge voltage falls below 40 V, the cathode heater is automatically turned off. From this point on, a wide range of options are available for beam current, beam voltage, neutralization, and biasing. A few of the typical modes are illustrated in Fig. 16. Although biasing is illustrated only for full beam power, the complete bias range of ±1 kV can be used with any beam current or voltage setting. Considering that the system can be operated as an ion source alone, as a neutralized ion source, and as an electron source alone, each with and without biasing, a total of 290 operating modes are available with SPIBS.

V. Conclusions

As a result of the work described in this paper, a satellite ion-ejection instrument has been designed and built. The flexibility of this instrument should make it a valuable tool in the study of satellite charging on SCATHA and on other space vehicles. The SPIBS design provides a life of more than 300 hours, and satisfies the SCATHA satellite instrument requirements on weight, power, EMI, and quality assurance. Demonstrated capabilities and features that contribute to the instrument's flexibility include:

1. Ability to eject an unneutralized ion beam having a current range of 0.3 mA to 2.0 mA at beam energies of 1 keV and 2 keV.
2. Ability to eject a partially or fully neutralized ion beam having the above current and voltage range.
3. Ability to bias the neutralized ion beam relative to satellite ground over the range of -1 kV to +1 kV.
4. Ability to emit electrons, without an ion beam from the neutralizer filament which can be biased from - 1 kV to +1 kV relative to satellite ground.
5. Ability to detect neutralizer emission and net currents (ions or electrons) between the SPIBS instrument and satellite ground down to a level of 2 μA.
6. Operation with xenon to avoid possible expellant interactions with the satellite.
7. Provisions for ground operation of the ion source and system during the satellite integration phase.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to the many SPIBS program participants for their dedication to this work. In particular, HRL staff members D. J. Hopper and N. Buck for PPA design and testing; Seiji Kami for ion source and mechanical design; J. D. Thompson for ion source testing; and C. R. Collett for system integration. W. P. Lynch of AFGL provided valuable assistance in developing the mechanical design, the blowoff cover, and interface requirements. W. Huber of Tri-Con Associates, Inc., tirelessly assisted AFGL and HRL in reviewing power processor designs and in preparing interface documents.

REFERENCES

1. DeForest, S. E., "Spacecraft Charging at Synchronous Orbit," Journal of Geophysical Research, Vol. 77, No. 4, p. 651 - 659, 1972.
2. Fredricks, R. W., and Scarf, F. L., "Observations of Spacecraft Charging Effects in Energetic Plasma Regions," Photon and Particle Interactions with Surfaces in Space, D. Reidel Publishing Co., Dororecht-Holland, p. 277 - 308, 1973.
3. Rosen, A., "Large Discharges and Arcs on Spacecraft," AIAA Astronautics and Aeronautics, p. 36 - 44, June 1975.
4. McPherson, D. A., Cauffman, D. P., and Schober, W., "Spacecraft Charging at High Altitudes - The SCATHA Satellite Program," AIAA Paper 75-92, AIAA 13th Aerospace Sciences Meeting, Pasadena, California, January 1975.
5. Bartlett, R. O., DeForest, S. E., and Goldstein, R., "Spacecraft Charging Control Demonstration at Geosynchronous Altitude," AIAA Paper 75-357, 11th Electric Propulsion Conference, March 1975.
6. DeForest, S. E. and Goldstein, R., "A Study of Electrostatic Charging of ATS-5 Satellite During Ion Thruster Operation," Final Technical Report, Contract NAS JPL 953675, Jet Propulsion Laboratory, Pasadena, California, December 1973.
7. Worlock, R., Davis, J. J., James, E., Ramirez, P., and Wood, O., "An Advanced Contact Ion Microthruster System," AIAA Paper 68-552, AIAA 4th Propulsion Joint Specialist Conference, Cleveland, Ohio, June 1968.
8. Hyman, J., Dulgeroff, C. R., Kami, S., and Williamson, W. S., "One-Millipound Mercury Ion Thruster," Journal of Spacecraft and Rockets, Vol 13, June 1976, p. 366 - 372.
9. Hyman, J., "Development of a 5-cm Flight Qualified Mercury Ion Thruster," Journal of Spacecraft and Rockets, Vol 10, August 1973, p. 503 - 509.